

# HPCBS

## High Performance Commercial Building Systems

### Control System Design Guide and Functional Testing Guide for Air Handling Systems: Public Release at NCBC 2003

*Element 5—Integrated Commissioning and Diagnostics  
Project 2.1 Commissioning and Monitoring for New Construction*

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**May 2003**

Published in the 11<sup>th</sup> National Conference  
on Building Commissioning proceedings.



This work has been supported by:

The California Energy Commission's (CEC) , Public Interest Energy Research Program, under Contract No. 400-99-012.

The Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Building Technologies Program of the U.S. Department of Energy (DOE) under Contract No. DE-AC03-76SF00098.

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## **Control System Design Guide and Functional Testing Guide for Air Handling Systems: Public Release at NCBC 2003**

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### **Synopsis**

As building systems grow increasingly complex and have tighter construction schedules, designers and commissioning providers need practical tools to help streamline the process and ensure performance. The ***Control System Design Guide*** and the ***Functional Testing Guide for Air Handling Systems: From the Fundamentals to the Field*** are two such tools. This paper provides an overview of the first public release of the Control System Design Guide and the Functional Testing Guide. A copy of the public release is available at the NCBC 2003 conference.

The Control System Design Guide provides a toolbox of templates for improving control system design and specification. It provides recommendations for the control system design process, guidelines for control and monitoring points, and sample points lists for 11 different system configurations. The Functional Testing Guide for Air Handling Systems provides both a practical understanding of the fundamentals of air handling systems and a detailed explanation of functional testing benefits and field tips. The Functional Testing Guide also reviews the energy and performance implications of common problems and provides links to publicly available functional test procedures in the Commissioning Test Protocol Library (CTPL).

### **About the Author(s)**

David Sellers is a senior project engineer at PECI with over 25 years of experience in HVAC system design and analysis. He has done fieldwork consisting of trouble-shooting, system optimization, control programming, testing and balancing, energy auditing and commissioning. He has worked on new construction, renovations, and retrofit projects in health care, institutional, commercial, and industrial facilities. His expertise includes developing and implementing new designs and system modification strategies to reduce energy consumption in both new and existing buildings. Mr. Sellers previously worked as an HVAC and Fire Protection engineer at Komatsu Silicon America, Inc., as a mechanical designer at McClure Engineering Associates, Inc., as a Systems Engineer for a controls manufacturer, and as a project engineer for a mechanical contractor/design build firm. At PECI, Mr. Sellers has led numerous commissioning projects, including the LEED™ Gold-rated Honda NW Regional Facilities and the new Seattle Federal Courthouse. In addition to commissioning projects, he has presented

many workshops on commissioning and has led the development of the Functional Testing Guide and Control System Design Guide.

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## Introduction

As building systems grow increasingly complex and have tighter construction schedules, designers and commissioning providers need practical tools to help streamline the process and ensure performance. The ***Control System Design Guide*** and the ***Functional Testing Guide for Air Handling Systems: From the Fundamentals to the Field*** are two such tools.

Control systems are often the most problematic part of a building. A good design process, taking into account maintenance, operation, and commissioning, can lead to a smoothly operating and efficient building. To this end, the Control System Design Guide provides a toolbox of templates for improving control system design and specification. The Design Guide provides recommendations for the control system design process, guidelines for control and monitoring points, and sample points lists for 11 different system configurations.

The Functional Testing Guide for Air Handling Systems provides both a practical understanding of the fundamentals of air handling systems and a detailed explanation of functional testing benefits and field tips. The Functional Testing Guide also reviews the energy and performance implications of common problems. In previous work, Pacific Gas and Electric Company gathered non-copyrighted functional test procedures to form the Commissioning Test Protocol Library, or CTPL. The Functional Testing Guide provides easy access to the test procedures in the CTPL using hyperlinks, and includes additional procedures written specifically for the Guide.

At NCBC 2001, the concept of the Functional Testing Guide was discussed at a working session entitled, “Commissioning Test Protocol Library”. While considerable work had been done to gather and review existing functional testing procedures, the group agreed that the missing link was an explanation of these procedures to help streamline their use. Since NCBC 2001, the Functional Testing Guide has evolved to serve this purpose in a way that is both comprehensive and user-friendly.

The Control System Design Guide and Functional Testing Guide were written by Portland Energy Conservation, Inc. (PECI), with funding from the California Energy Commission’s Public Interest Energy Research program and the US Department of Energy’s Office of Building Technology. This work has been supported under contract to Lawrence Berkeley National Laboratory. If you are interested in obtaining a CD copy or downloading the Guides from LBNL’s website, please contact PECI. A free copy of the Guides on CD will be available at the NCBC 2003 conference.

## **Part I: The Control System Design Guide**

The *Control System Design Guide* (Design Guide) provides methods and recommendations for the control system design process, monitoring and control point selection, and installation. Control systems are often the most problematic system in a building. A good design process that takes into account maintenance, operation, and commissioning can lead to a smoothly operating and efficient building. To this end, the Design Guide provides a toolbox of templates for improving control system design and specification.

HVAC designers are the primary audience for the Design Guide. The control design process it presents will assist HVAC designers in producing well-designed control systems that achieve efficient and robust operation. The spreadsheet examples for control valve schedules, damper schedules, and points lists can streamline the use of the control system design concepts set forth in the Design Guide by providing convenient starting points from which designers can build. Although each reader brings their own unique questions to the text, the Design Guide contains information that designers, commissioning providers, operators, and owners will find useful.

### **Chapter 2 Control System Design Process**

A bird's eye view of the design process describes the different demands placed on designers, contractors, and owners. Topics covered include the importance of system diagrams, detailed sequences of operation, points lists, and detailed specifications. Spreadsheet templates are provided to streamline the design and specification process of control points, valves, and dampers. Completed spreadsheet templates are also included as examples.

### **Chapter 3 Selection and Installation of Control and Monitoring Points**

Guidelines help designers make decisions about control and monitoring point selection to improve efficiency and control over the life of the building. Detailed discussion of common sources of measurement error will help designers avoid these problems in their designs and help commissioning providers interpret inaccuracies in field measurements. Recommendations for selecting and installing temperature, humidity, pressure, and flow sensor technologies guide both designers and commissioning providers through the ever-changing world of sensors. Figure A below illustrates the technology summary and application detail format that is provided for all sensor types. Recommendations for interfacing points to the building automation system (BAS) includes discussion of point naming conventions, settings, alarms, display graphics, and trending.

### **Chapter 4 System Configurations**

This chapter describes 12 common air handling system configurations and recommends the monitoring and control point requirements associated with each configuration. These point requirements are included as annotated points lists in Microsoft Excel that can be used by designers and commissioning providers as a starting point on their own projects.

### 3.5.4. Pressure and Flow

Table 3.3 presents a variety of pressure measurement technologies for air and water. The capacitance, strain gauge, and piezoresistive technologies compete with each other since they offer accuracy at a reasonable cost in a variety of levels of quality. LVTDs compete with the lower end versions of these technologies. For all of these devices, pressure transients in the air or water may cause erroneous readings. For example, pressure pulses from the pumps can create noise in the pressure measurement. A pressure pulse can also be created from a door near a diffuser location and near the duct static pressure measurement point. Pressure pulses or pressure pulse can cause the control loop to hunt.

**Table 3.3 Pressure Measurement Technologies**

Technology	Function	Advantages	Disadvantages
<b>Velocity Probes</b> <i>Example application: isolation rooms</i>	Measure pressure differential based on velocity through a tube across the pressure difference.	Can accurately and repeatably measure to thousandths and ten thousandths of an inch water column; good for low pressure applications like clean rooms, control and monitoring or pressure differentials in the range of 0.05 in.w.c. or less must be accurately measured and maintained.	More expensive than other technologies, sensing line length critical since there is active flow through the lines - long lines could impact the accuracy of the input because the pressure drop through them would affect the flow and flow is the indicator used to measure pressure differential.
<b>Manometer</b> <i>Example application: filter pressure drop</i>	Measure the change in height of a column of liquid between a reference pressure and the pressure being measured. Typically a manual instrument used to calibrate and verify other instruments.		
<b>Capacitance</b>	Pressure changes cause a change in capacitance between a metal diaphragm and an electrode. The capacitance is measured and used to generate an output signal.		
<b>Strain Gauge</b>	The deflection of a diaphragm due to pressure change is measured by strain gauges.		
<b>Piezoresistive</b>	A pressure change causes the resistance of a semiconductor (solid-state chip) to vary.		
<b>Linear Variable Differential Transformer (LVDT)</b>	An electric output is produced in proportion to the displacement of a movable transformer core. Usually coupled to a bourdon tube to measure pressure.		

#### 3.5.1. Space temperature

**Accuracy**  $\pm 1^\circ\text{F}$  to  $\pm 1.5^\circ\text{F}$

#### Installation

Locate the sensor away from electronics and other heat sources. Avoid locations where air diffusion may be stagnant. Also avoid exterior walls and stud cavities that connect to plenum floors since infiltration and surface wall surface temperatures can affect what the sensor is reading. It may be necessary to completely insulate the mounting box or mount the thermostat on an insulating pad. It is also important to make sure that small jets of air created by infiltration or pressurized air from a plenum exiting through the stud cavity and hitting the sensor are eliminated.

#### Calibration

Calibrate sensor if complaint or troubleshooting calls warrant and/or based on sensor drift specifications from the manufacturer. For instance a lower quality thermistor may show a drift of  $0.1^\circ\text{F}$  per year, which could add up over 5-10 years. If a space never seems to come under control, it's probably worth going and taking a look. You may discover that the sensor is accurately reporting what it is seeing, but its being influenced by a draft, infiltration or cold surface.

#### 3.5.1.2. Duct temperature

Differential pressure-based flow readings are a function of the square of the flow (at 50% of full flow, the signal is 25% of full flow). If differential pressure is measured at a high turndown, the signal is 25% of full flow.

**Accuracy**  $\pm 0.5^\circ\text{F}$  to  $\pm 1.5^\circ\text{F}$

#### Installation

Higher velocities will improve response time due to improved convective heat transfer characteristics. Averaging sensors need to see uniform mass flow rates to reflect a true average temperature.

#### Calibration

Sensor error leads to energy waste (see sidebar above – [Implications of Inaccurate Temperature Sensors](#)). Calibrate per the manufacturers recommendations, or at least annually if no standards exist.

If it is an averaging sensor, the practical tolerance is  $1.5^\circ\text{F}$ . See the averaging sensors discussion below. On large systems, tighter tolerances are desirable because the energy waste from small errors can be considerable over time.

**Figure A: Control System Design Guide Chapter 3 Excerpt**

## Part II: The Functional Testing Guide

The *Functional Testing Guide for Air Handlers: From the Fundamentals to the Field* (Functional Testing Guide) provides both a practical understanding of the fundamentals of air handling systems and field tips for functional testing. The Functional Testing Guide also reviews the energy and performance implications of common problems and provides links to functional test procedures in the public domain.

The Functional Testing Guide allows easy access to the many functional tests collected in the *Commissioning Test Protocol Library* (CTPL) developed by Pacific Gas & Electric Company. The CTPL is the largest existing collection of functional test procedures, including many non-copyrighted procedures that can be customized to suit individual system configurations. Since the test procedures in the CTPL do not include detailed explanations, the Functional Testing Guide explains the “how” and “why” behind the functional tests in the CTPL. Understanding the reasoning behind test procedures and how to interpret and act upon the results is essential for successful testing.

Together, the Functional Testing Guide and the CTPL will help commissioning providers standardize their functional testing procedures and improve quality control, two issues which continue to burden the commissioning industry. Commissioning providers are the primary audience for the Functional Testing Guide and the CTPL. The Functional Testing Guide also covers design issues as a basis for design review, and to help identify solutions for failed functional tests and educational material about each component of air handling systems. This information will help commissioning providers:

- Understand how to test from a systems perspective
- Identify common problems and the root causes of these problems
- Customize test procedures to meet the needs of their specific projects
- Understand why a specific test sequence is being executed
- Understand the possible outcomes and necessary precautions for the test sequence
- Understand the costs and benefits of the test sequences

The commissioning providers using the Functional Testing Guide should already be familiar with the commissioning process, HVAC fundamentals, and the building construction process and industry.

### Chapter Summaries

#### **Chapter 2: Functional Testing Basics**

The first chapter of the Functional Testing Guide covers the general functional testing concepts that underlie all subsequent chapters. Basic concepts that are given only minor treatment during later chapters are covered in detail here. This chapter includes an introduction to the system approach, a fundamental way of looking at the components of an HVAC system as a whole.

Other topics include the testing hierarchy, training, verification checks, useful tools, functional test procedure components, precautions, and test preparations.

### **Chapters 3 – 18: Air Handler Components**

These chapters cover the functional testing of each component of an air handler, from the outdoor air intake section to the exhaust air discharge point. Regardless of the system configuration, the functional testing associated with a component is similar. For example, a preheat coil in a variable volume system performs the same function as it would in a constant volume system. Components included in Chapters 3 - 18 are as follows:

- Outdoor air intake (Chapter 3)
- Fan casing (Chapter 4)
- Economizer and mixed air (Chapter 5)
- Filtration (Chapter 6)
- Preheat (Chapter 7)
- Cooling (Chapter 8)
- Humidification (Chapter 9)
- Reheat (Chapter 10)
- Warm-up (Chapter 11)
- Fans and drives (Chapter 12)
- Distribution (Chapter 13)
- Terminal equipment (Chapter 14)
- Return, relief and exhaust (Chapter 15)
- Scrubbers (Chapter 16)
- Management and control of smoke and fire (Chapter 17)
- Integrated operation and control (Chapter 18)

These chapters will help commissioning providers, building operators, and owners identify and solve problems on paper during design and in the field. Each chapter contains links to relevant test procedures from the CTPL and other additional test procedures, which give commissioning providers easy access to all publicly available tests. The tests from each chapter can be combined and customized to suit specific system configurations. Although each chapter covers a different component of the air handling system, they all follow the same format:

- **Table of Contents** The table of contents allows the user to quickly assess the chapter's content and jump to topics of interest.
- **Theory and Applications** This section provides general insight and theory regarding the typical applications of the component or system.

- **Functional Testing Benefits** The benefits associated with testing the component are described, including energy and resource savings, reliability issues, and indoor environmental quality issues.
- **Functional Testing Field Tips** Practical, field-tested functional testing information includes:
  - 1) Purpose of the Test
  - 2) Instrumentation Required
  - 3) Test Conditions
  - 4) Time Required to Test
  - 5) Acceptance Criteria
  - 6) Potential Problems and Cautions
- **Design Issues Overview** This insightful look at how the design parameters affect the outcome of functional testing also supports the design review process. Currently, this table has been completed for following components: Cooling, Humidification, Reheat, Warm-up, Fans and Drives, Distribution.
- **Typical Problems** Important problems normally uncovered during testing or design review are highlighted. Currently, this section has been completed for the following components: Preheat, Cooling, Reheat, Warm-up, Fans and Drives.
- **Non-copyrighted Tests** Hyperlinks provide access to the CTPL test procedures and, in some cases, additional test procedures created for the Functional Testing Guide. The tests can be edited to serve a specific project or as the basis for development of a new test procedure. The structure of the Functional Testing Guide allows the user to extract tests from the applicable component chapters to develop a comprehensive procedure for a real air handling system. The Functional Testing Guide is a work in progress, and future versions will contain additional test procedures to supplement those currently available in the Functional Testing Guide and the CTPL. Figure B below is an example of the functional testing support provided and how the information is linked to a test procedure.
- **Supplemental Information** Supplemental information describes the fundamental concepts behind the component under discussion. The extent to which this information has been developed will vary from chapter to chapter. Chapter 5: Economizer and Mixed Air and Chapter 13: Distribution includes a more complete presentation of supplemental information.

## **Appendices**

The Functional Testing Guide features three Appendices:

- **Appendix A Overview of the Commissioning Test Protocol Library** provides direct links to all publicly available test procedures available in the library. While links to each of these procedures have been included in the appropriate Functional Testing Guide chapters, the links are provided in one place as Appendix A for convenience.
- **Appendix B Resources** provides a list of resources that will be useful for further reference.
- **Appendix C Calculations** is the main component of the cost-benefit analysis for the Functional Testing Guide. Currently, the calculations for fan energy savings associated with static pressure reductions have been fully developed and serve as a model for additional calculations that are will be referenced. Spreadsheets with these calculations are also provided to help streamline their use.

## Functional Testing Supporting Information

### Relative Calibration Functional Test Description

The Relative Calibration Test is an example of a fully developed test to supplement a gap identified in the Commissioning Test Protocol Library.

The purpose of the test is to ensure the relative accuracy of a group of sensors associated with a system or selected portion of a system where errors related to the calibration accuracy window of the sensors could cause energy to be wasted or operating data to be misinterpreted.

Functional Test Form is a functional test form for relative calibration. The below describe this test form.

### Hyperlink to sample procedure and test template

#### Functional Testing Benefits

Benefit	Comments
<b>Energy Efficiency Related Benefits</b>	1. Minimizes the potential for simultaneous heating and cooling due to the specific operating point of sensors with-in their accuracy window.
<b>Other Benefits</b>	1. Improves system operability by eliminating false indications of temperature differences that do not exist. For instance, after relative calibration, a temperature rise across a coil that is measured as too high really will be an indicator of poor performance. 2. Improves system performance by minimizing misrepresenting what is actually going on in the system, either manually or automatically.

### Relative Calibration Functional Test

**Instructions:** For each system included on the checklist, verify the items indicated using **Yes** for acceptable, **No** for unacceptable, or **NA** for Not Applicable. For unacceptable items, identify what is required to correct the problem in the comments area provided. Use numbers to refer to comments. Identify the responsible contractor, if know, for any items requiring further action.

#### Equipment Required:

1. Field thermometer of some sort.
2. Lab grade thermometer (Optional, but highly desirable)
3. Minute by minute trending of points to be tested (Optional)
4. Shortridge meter with temperature probe (Optional but if available can be used as the field thermometer)

**Acceptance Criteria:** This test places the system in a steady state operating mode and then adjusts the return air temperature sensor, the mixed air temperature sensor, the warm-up coil discharge temperature sensor and the air handling unit discharge temperature sensor so that they read the same value when subjected to the same operating condition. Acceptance criteria are as follows:

1. With the system in a steady state condition, all sensors read the same value relative to a baseline, with-in their accuracy tolerance prior to adjustment.
2. With the system in a steady state condition, all sensors read the same value after adjustment.

The test will be performed at two different temperature levels in an effort to provide consistent readings from these sensors under all normally encountered operating conditions.

**Date(s) of Test:** \_\_\_\_\_

**Time(s) of Test:** \_\_\_\_\_

**Test Technician** \_\_\_\_\_

#### Functional Testing Field Tips

Item	Comments
<b>Purpose of Test</b>	The purpose of the test is to ensure the relative accuracy of sensors associated with a system or selected portion of a system where errors related to the calibration accuracy window of the sensors could cause energy to be wasted or operating data to be misinterpreted.
<b>Instrumentation Required</b>	The fundamental test can be performed with the sensors that are being tested. However, it is helpful to establish the baseline for comparison. Minute by minute trending or data logging can be useful to document the test results. A Shortridge probe makes checking the average mixed air temperature easier.
<b>Test Conditions</b>	The system needs to be placed in a steady state condition. The parameter measured by the sensors undergo process can be assumed to be uniform at all system under test.
<b>Time Required to Test</b>	Test times will vary from 15 minutes to an hour.

Relative Calibration Test

Item Number	Requirement	Initial and Date when Complete
<b>Prerequisites</b>		
1	Verify that all applicable prestart and start-up verification checks from the equipment manufacturer have been completed and that the system is fully functional.	
2	Verify that the sensors that are to be tested are certified and installed per the accuracy requirements of the specifications.	
3	Visually inspect the sensors that are to be tested to verify that they are installed in a manner that will allow them to measure the parameter intended and are free from influences due to mounting arrangement or configuration.	
4	Verify that the loads served by the system can tolerate the 15 to 60 minute period of operation with out active discharge temperature control that is required to perform this test.	
5	Target a day for the test when it is anticipated that the outdoor conditions will be in the mid 50°F range and suitable for operating on 100% outdoor air with out the need to heat or cool. This will allow calibration at two operating points. If the test cannot be scheduled for such a day prior to substantial completion, then proceed with the test in the full recirculation mode only.	
<b>Preparation</b>		

Relative Calibration Test

1

**Figure B:** Functional Testing Guide Example Test Excerpt

## Next Steps

The Functional Testing Guide for Air Handling Systems has received high marks within the commissioning and energy efficiency industry for filling a need for functional testing education. Draft versions were distributed to well over 30 users, from commissioning providers to operators to researchers, and feedback was compiled. The proposed enhancements described below draw upon this reviewer feedback.

This reviewer feedback, while highly positive, alerted us to the importance of developing additional functional test procedures that are not available for the air handling system in the Commissioning Test Protocol Library (CTPL). In the CTPL, there are only three main sources of functional tests in the public domain - about 25 tests in all. These tests do not cover many of the testing issues described in the Functional Testing Guide. For the Functional Testing Guide to be most useful to commissioning providers, it needs to fill these gaps by incorporating the most critical test procedures that are not covered in the CTPL.

Commissioning providers, owners, and operators consistently express interest in educational material that provides a better understanding of testing for integrated system operation. Integration of systems is the cornerstone of commissioning due to its complexity and importance to overall system performance. Test protocols targeted at integrated performance can be some of the most difficult and complex protocols to develop and implement because:

- Successful integrated performance is highly dependent on the successful performance of the individual elements
- Integrated performance can involve complex interactions that are often difficult to understand and interpret.
- Tracking the interactions that occur during an integrated performance test is often a challenge.

The structure of the Functional Testing Guide has been arranged to lead the user from the simple to the complex by first describing the function and testing of the individual components of the system. However, the testing for the two major points of integration for the air handling system, the terminal equipment and the overall integrated operations and control have not been developed beyond an introductory level. Terminal equipment commissioning can account for a large amount of energy savings due to correcting the reheat and airflow problems that are typically found. The Functional Testing Guide needs to include the level of system-integration detail that is desired by the Guide users.

In the enhanced Functional Testing Guide, the educational information in Chapter 14: Terminal Equipment and Chapter 18: Integrated Operation and Control will be developed to address these issues. The educational material will include relevant calculations (incorporated into Appendix C: Calculations), the functional tests developed to address gaps in the CTPL, and critical educational topics.

## **Conclusion**

These tools for improving control system design and streamlining the functional testing process can help designers and commissioning providers turn over well-functioning buildings to owners and operators. Using the spreadsheet tools and controls recommendations within the Control System Design Guide will help level the playing field for providing quality controls installations that meet design and commissioning requirements. By using the Functional Testing Guide, new commissioning providers and commissioning veterans alike can gain a deep understanding of common problems, the benefits of fixing the problems, and details about how to functionally test the system to find these problems. In the process of promoting the fundamentals of HVAC design and commissioning, these Guides bring the fundamentals to life through field tips and anecdotes. A free copy of these Guides on CD will be available at the NCBC 2003 conference, and a download will be available through the following website:  
<http://buildings.lbl.gov/hpcbs/Pubs.html>.